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Executive functions do not underlie performance on the Edinburgh Social Cognition Test (ESCoT) in healthy younger and older adults

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Abstract

Objective: Current measures of social cognition have shown inconsistent findings regarding the effects of executive function (EF) abilities on social cognitive performance in older adults. The psychometric properties of the different social cognition tests may underlie the disproportional overlap with EF abilities. Our aim was to examine the relationship between social cognition and EF abilities using the Edinburgh Social Cognition Test (ESCoT; Baksh et al., 2018), a test assessing four different aspects of social cognition: cognitive theory of mind (ToM), affective ToM, interpersonal understanding of social norms and intrapersonal understanding of social norms**. Method:** We administered the ESCoT, EF measures of inhibition, set-shifting, updating, and a measure of processing speed, to 30 younger and 31 older adults. We also administered the Visual Perspective Tasking task (VPT) as a ToM test thought to be reliant on EF abilities. **Results:** Better performance on cognitive ToM was significantly associated with younger age and slower processing speed. Better performance on affective ToM and ESCoT total score was associated with being younger and female. Better performance on interpersonal understanding of social norms was associated with being younger. EF abilities did not predict performance on any subtest of the ESCoT. In contrast, on the VPT, the relationship between age group and performance was fully or partially mediated by processing speed and updating. **Conclusions:** These findings show that the ESCoT is a valuable measure of different aspects of social cognition and, unlike many established tests of social cognition, performance is not predicted by EF abilities.

Keywords: Edinburgh Social Cognition Test (ESCoT), executive functions, aging, Theory of Mind, understanding of social norms

Introduction

Social cognitive abilities are higher-order cognitive processes used to process and interpret social information to successfully interact with others (Adolphs, 2009; Henry, Phillips, Ruffman, & Bailey, 2013). Such abilities include cognitive theory of mind (ToM; the ability to make inferences about the thoughts, intentions and beliefs of others), affective ToM (i.e., the ability to make inferences about the feelings of others), understanding of social norms, moral judgement and empathy (Baez et al., 2013; Love, Ruff, & Geldmacher, 2015).

With an increasingly aging population, it is vital to examine whether social cognition shows the same age-related changes found in other cognitive domains (Hedden & Gabrieli, 2004; Salthouse, 2009). Understanding the impact of age on social cognition is important since social cognition is associated with real-world social functioning such as close social network size (Radecki, Cox, & MacPherson, 2019; Stiller & Dunbar, 2007) and the number of relationships individuals maintain (Kardos, Leidner, Pléh, Soltész, & Unoka, 2017). This is particularly relevant for aging populations due to the high levels of loneliness observed in older adults (Victor & Yang, 2012).

Studies examining age-related differences in social cognition have yielded inconsistent results. Some have shown that older adults perform poorer than younger adults (Bailey, Henry, & Von Hippel, 2008; Baksh, Abrahams, Auyeung, & MacPherson, 2018; Bottiroli, Cavallini, Ceccato, Vecchi, & Lecce, 2016; Henry et al., 2013; Moran, Jolly, & Mitchell, 2012). However, others have shown no differences (Castelli et al., 2010; Keightley, Winocur, Burianova, Hongwanishkul, & Grady, 2006; Li et al., 2013; MacPherson, Phillips, & Della Sala, 2002; McKinnon & Moscovitch, 2007; Phillips, MacLean, & Allen, 2002; Y. Wang & Su, 2006) or even improved performance in older adults compared to younger adults (Happé, Winner, & Brownell, 1998).

Age-related changes in social cognition may be the result of impairments in other cognitive abilities (Bernstein, Thornton, & Sommerville, 2011). It is well-documented that older adults' executive functions (EF) decline with age (Craik & Salthouse, 2011; Hedden & Gabrieli, 2004; Salthouse, 2009). There is also evidence from studies of older adults (Bradford, Brunsdon, & Ferguson, 2016, 2017; Phillips et al., 2011) and patients (Apperly, Samson, & Humphreys, 2005) that EF abilities are important for performance on social cognition tests.

In particular, EF abilities appear to mediate the effect of age on ToM performance. Bottiroli et al. (2016) found that cognitive ToM performance, assessed using the Faux Pas test (Stone, Baron-Cohen, & Knight, 1998), was correlated with age, updating and inhibition, with updating mediating the effect of age on cognitive ToM performance. Similarly, updating partially mediates age-related differences in false-belief (Phillips et al., 2011) and explains the variance in performance on the Strange Stories Film Task (while age does not) (Johansson Nolaker, Murray, Happé, & Charlton, 2018). Inhibition has been found to mediate age-related differences on false belief (Li et al., 2013) and belief-desire reasoning tasks (German & Hehman, 2006). When Bailey and Henry (2008) considered both cognitive and affective ToM using false-belief reasoning and the Reading the Mind in the Eyes (RME) tests respectively (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001), inhibition mediated age-related differences in cognitive ToM but only partially mediated age differences in affective ToM. Inhibition, updating, and set-shifting have also been found to mediate the relationship between age-related differences on the Strange Stories Test (Charlton, Barrick, Markus, & Morris, 2009). Therefore, some evidence suggests that the variance in ToM performance in older adults is explained by EF abilities.

Yet, other studies report that age-related differences on ToM tests are independent of EF abilities. Using story-based tests, age-related differences in cognitive ToM remained significant when considering EF abilities (Cavallini, Lecce, Bottiroli, Palladino, & Pagnin, 2013; Maylor, Moulson, Muncer, & Taylor, 2002; Wang & Su, 2013). Moreover, Bernstein et al. (2011) showed that age, but not EF abilities, significantly contributed to variance on a continuous false-belief task. On affective ToM, performance on the RME was not related to age-related declines in inhibition, set-shifting or updating (Duval, Piolino, Bejanin, Eustache, & Desgranges, 2011) and there were no age-related differences in inhibitory control on the Cambridge Mindreading Face-Voice Battery (Mahy et al., 2014). Other studies have also failed to show that age-related declines in affective ToM are explained by EF performance (Keightley et al., 2006; Sullivan & Ruffman, 2004; Wang & Su, 2013). Therefore, it is unclear whether age-related changes in social cognition are the result of impairments in EF abilities or they occur independently (Bernstein et al., 2011).

One aspect of ToM which has been examined less in relation to EFs in older adults is perspective taking (i.e., the selection of a specific perspective, self versus other). In particular, individuals demonstrate biases towards their own perspective (Samson, Apperly, Kathirgamanathan, & Humphreys, 2005); consequently when asked to complete tests which require making ToM inferences about another individual, effortful processing is required (Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010), including inhibitory control (Decety et al., 1997; Kemp, Després, Sellal, & Dufour, 2012). Therefore, age-related differences in perspective taking may be dependent on declines in EF abilities.

The inconsistencies across aging studies may be due to the types of social cognition test administered. Previous research have shown that performance on different social cognition tests is associated with other cognitive processes such as verbal comprehension and perceptual reasoning (Baker, Peterson, Pulos, & Kirkland, 2014; Charlton et al., 2009; Maylor et al., 2002; Sullivan & Ruffman, 2004). For instance, Charlton et al. (2009) found that the association between age and ToM abilities measured by the Strange Stories test was fully mediated by perceptual reasoning and partially mediated by verbal comprehension. Further studies have found correlations between ToM and verbal abilities (Maylor et al., 2002) and have shown that perceptual reasoning accounts for age-related differences on the Strange Stories test (Sullivan & Ruffman, 2004). Therefore, the psychometric properties of the different ToM tests may underlie the disproportional overlap with EF abilities in older adults.

Our primary aim was to further examine the relationship between social cognition and EF abilities using our new test of social cognition called the Edinburgh Social Cognition Test (ESCoT; Baksh et al., 2018). The ESCoT is an animation-based test that assesses four different aspects of social cognition in the same test: cognitive ToM, affective ToM, interpersonal understanding of social norms and intrapersonal understanding of social norms. We considered the ESCoT as an ideal test to explore the relationship between ToM, as well as other aspects of social cognition, and EF abilities because, unlike other tests, performance on the subtests of the ESCoT are not affected by perceptual reasoning abilities or verbal comprehension performance (Baksh et al., 2018). Therefore, any relationship between social cognitive abilities and EFs would be independent of these factors. Furthermore, an important feature of social cognition not typically examined in the aging literature is the ability to understand social norms from interpersonal and intrapersonal perspectives. In one of the few studies to examine social norm understanding, Halberstadt, Ruffman, Murray, Taumoepeau, and Ryan (2011) found that older adults were poorer at discriminating between socially appropriate and inappropriate behaviours from short videos of social interactions compared to younger adults. The ESCoT provides an opportunity to study the relationship between social norm understanding and EF. Finally, we included the Visual Perspective Tasking task (VPT) developed by Samson et al. (2010) to include a ToM test thought to be reliant on EF abilities to compare with the ESCoT in the same groups of younger and older adults.

Method

Participants

Sixty-one participants were recruited through online advertisements and a research volunteer panel at the Department of Psychology, University of Edinburgh. Participants were subdivided into two age groups: 30 younger adults (20–31 years old, 12 males) and 31 older adults (65–80 years, 16 males). The mean age was 22.57 years (SD = 2.36) for the younger group and 72.29 years (SD = 3.99) for the older group. The younger and older age groups did not significantly differ in years of full-time education (M = 16.73, SD = 1.14; M = 16.12, SD = 3.27 respectively, p = 0.22). Participants were native English speakers, with corrected to normal vision and hearing, and normal colour vision. No participant self-reported any history of neurological or psychiatric disorders based on exclusion criteria listed in the Wechsler Adult Intelligence Scale-IV (WAIS-IV; Wechsler, 2008). Written informed consent was obtained from each participant. This study was approved by the School of Philosophy, Psychology and Language Sciences Research Ethics Committee, University of Edinburgh (Reference number: 208-1617/8).

Measures

Edinburgh Cognitive and Behavioural ALS Screen (ECAS). The ECAS (Abrahams et al., 2014) is a commonly used screening measure of general cognitive functioning. It assesses language, verbal fluency, executive functioning, memory and visuospatial abilities. Higher scores demonstrate better performance and the published cut-off for atypical performance is 105 out of 136.

Edinburgh Social Cognition Test (ESCoT). The ESCoT (Baksh et al., 2018) is an animation-based measure of social cognition. It assesses four social cognitive abilities:

cognitive ToM; affective ToM; interpersonal understanding of social norms; and intrapersonal understanding of social norms, using self-contained contextually driven social interactions (see Table 1). It consists of 11 social interactions in total: one practice, 5 interactions involving social norm violations and 5 interactions without social norm violations. Each interaction consists of 5 questions: a general comprehension question and 4 questions assessing each social cognitive ability.

The animation was presented in the middle of a computer screen and at the end of each animation, a static storyboard depicting a summary of what occurred in the interaction was presented onscreen. This storyboard remained onscreen while participants answered questions relating to the interaction. Participants were asked a general comprehension question (which was not scored) where they described what they saw in the interaction. Participants were then asked one question to assess each of the four subtests of social cognition. To allow optimal interpretation of each interaction and to capture the quality of their response, participants were prompted if they gave a limited response or their response lacked important information from the interaction. They were prompted with the question, ‘Can you tell me more about what you mean by that?’ or ‘Can you explain that in a little bit more detail?’ Each participant was prompted only once for each question.

Each response was scored on the quality of the answer with emphasis on the interaction that occurred and the animation context. To achieve full marks, participants were required to extract and integrate the contextually relevant information into their response. Of note, the most important aspect of participants’ responses was the quality of their answer, not the length. For the intrapersonal understanding of social norms questions, full marks were given for responses which highlighted the subtle social nuances of the interaction rather than personal attributes of the participants. Each question was awarded a maximum of 3 points, resulting in a score of 12 points for each social interaction and a maximum of 30 points for each subtest. The total maximum score for the test was 120 points, with higher scores indicating better performance.

[Insert Table 1 here]

Visual Perspective Taking Task (VPT). The VPT (Samson et al., 2010) is a computerised test in which participants are presented with a literal view of a room. Zero to 3 discs are presented on the walls. A human avatar is positioned in the centre of the room and always faced towards the left or right wall. In half of the trials, the avatar's point of view was consistent with the participant's view and, in the remaining trials, the avatar's point of view was inconsistent. The position of the avatar was always kept constant across both consistent and inconsistent conditions but the position of the discs changed.

At the beginning of each trial, participants saw a fixation cross for 750 ms, followed by the words 'YOU' or 'SHE' for another 750 ms, indicating which perspective they were to take (self-condition or other-condition). Subsequently, a number between 0 and 3 appeared on the wall for 750ms, to indicate the number of discs (perspective content) participants had to verify. Following a 500ms interval, an image of the avatar appeared and the participant had to respond as quickly and accurately as possible to whether the number they saw (0–3) matched the number of discs that could be seen from the 'YOU' or 'SHE' perspective (i.e., consistent or inconsistent). If no response was given within 2000ms, the next trial was presented. There were 4 conditions; self-consistent, self-inconsistent, other-consistent and other-inconsistent conditions.

On the 'yes' response trials (matching) for consistent and inconsistent conditions, the number onscreen matched the number of discs seen from the relevant perspective (self-condition or other-condition). On the 'no' response (mismatching) inconsistent trials, the number onscreen indicated the number of the discs that could be seen from the irrelevant perspective. For ‘no’ response (mismatching) consistent trials, the number onscreen did not correspond to either the self or other perspective. There was a block of 26 practice trials. The experimental trials were divided into 4 blocks of 52 trials (48 test and 4 filler trials) which were counter-balanced across participants. Only responses from correct trials were analysed (Samson et al., 2010) and processing costs based on Qureshi, Apperly, and Samson (2010) were calculated by dividing the mean response time by the proportion correct. Lower processing costs indicated better performance.

Delis-Kaplan Executive Function System (D-KEFS) Colour-Word Interference Test. The D-KEFS colour-word interference test (Delis, Kaplan, & Kramer, 2001) was administered to measure inhibition. In the first condition, participants were asked to name aloud a sequence of coloured squares as quickly as possible. In the second condition, participants were required to read aloud the colour of words printed in black ink as quickly as possible. Finally, in the third (inhibition) condition, participants were presented with coloured words printed in an incongruent colour of ink (e.g., ‘GREEN’ printed in blue ink) and were asked to name the colour of the ink rather than reading the word itself as quickly as possible. Inhibition was measured by subtracting the time taken to complete the inhibition condition from the time taken to complete the word-reading condition. Lower scores indicated better inhibitory control.

Trail Making Test (TMT). The TMT (Reitan & Wolfson, 1993) is a pencil and paper test of set-shifting consisting of two parts. Part A required participants to connect a series of numbers in numerical order (e.g., 1-2-3-4) as quickly as possible without lifting the pencil from the paper. In Part B, participants were asked to alternate between connecting numbers and letters in numerical and alphabetical order (e.g., 1-A-2-B) as quickly as possible. Set-shifting was measured as the time taken to complete Part B minus the time taken to complete Part A. Lower scores indicated better performance.

Digit Span Sequencing Subtest from the Wechsler Adult Intelligence Scale (WAIS-IV). The digit span subtest (Wechsler, 2008) was administered to assess updating. It required participants to listen to a sequence of numbers and then reorder and recall the numbers in ascending order, starting with the lowest number (e.g., 8, 3, 5 into 3, 5, 8). The final score was the total number of correctly recalled trials, out of a maximum possible score of 16. Higher scores indicated better updating.

Coding Subtest from WAIS-IV. The coding subtest (Wechsler, 2008) was administered to measure processing speed (Salthouse & Ferrer-Caja, 2003). Participants were provided with a key that included 9 digits, each paired with a unique symbol. Participants were presented with digits and had to draw the matching symbols below the digits as quickly as possible. Each participant was given two minutes and correct responses were those drawn correctly in accordance with the digit-symbol key. Participants could achieve a maximum score of 135 points, with higher scores demonstrating faster processing speed.

Statistical Analysis

The relationship between performance on the ESCoT subtests, VPT and EF abilities were examined using multiple regression analyses. Similar to our previous paper (Baksh et al., 2018), in the first model, the background predictors (age group, gender, years of education) which significantly correlated with the outcome variables from the ESCoT and VPT at a pre-specified significance level of $p < 0.20$ were entered into the analysis (Altman, 1991) using the enter method. We chose a significance level of $p < 0.20$ over traditional levels since $p < 0.05$ can fail to identify variables known to be important to the outcome variable and simulation studies have shown that a cut-off of $p < 0.20$ yields better models (Bursac, Gauss, Williams, & Hosmer, 2008; Lee, 2014). We added processing speed (Model 2) and then our EF measures (inhibition, set-shifting and updating; Model 3) into the models using a stepwise method (entry criterion $p < 0.05$, removal criterion $p > 0.10$). Correlational analyses examined the relationship between the ESCoT and VPT. We used the raw scores for all social cognition and EF tests in our analysis to allow for examination of age-related changes. The alpha values were set at $p < 0.05$ and Holm correction was used to adjust for multiple comparisons. Finally, given our modest sample size, Bayesian analysis of covariance (ANCOVA) were conducted on the ESCoT outcome variables using JASP version 0.10 (JASP Team, 2018) to compare the strength of the evidence supporting the null model (including the significantly related control variables) and the alternative model (including processing speed and EF abilities) (Bayarri, Benjamin, Berger, & Sellke, 2016). Bayesian ANCOVA was used rather than Bayesian regression analyses as the models included binary (i.e., gender) as well as continuous variables. An estimated Bayes Factor (BF_{01}) provides a likelihood ratio of the probability of the data occurring under the null model over the probability of the data occurring under the alternative model. For instance, if $BF_{01} = 5$, the observed data are 5 times more likely to have occurred given the null hypothesis than the experimental hypothesis. Bayes Factors of above 3 provide "moderate" evidence, above 10 provide "strong" evidence, and above 30 provide "very strong" evidence (Lee & Wagenmakers, 2013).

Results

ESCoT data from one of the older participants were omitted due to being outliers. Data from a second older participant were omitted from the VPT analyses and another older adult's VPT other inconsistent condition data were removed as they were outliers. In the younger adult group, one participant's self-consistent, other consistent and other inconsistent processing costs data were removed due to being outliers, and another younger adult's self-inconsistent processing costs score was also removed.

Descriptive statistics and differences tests are reported in Table 2. The two age groups did not significantly differ on the ECAS. Older adults performed poorer than younger adults on EF abilities and processing speed. Older adults exhibited poorer performance on cognitive ToM, affective ToM, interpersonal understanding of social norms and ESCoT total scores compared to younger adults. There was no age-related difference in intrapersonal understanding of social norms. On the VPT, older adults produced significantly larger processing costs than younger adults in all conditions.

[Insert Table 2 here]

Correlational analyses between the background variables and ESCoT subtests and VPT revealed that years of education did not correlate with any variable (p > 0.20) and was not included in the regression analyses. Gender did not correlate with cognitive ToM (p > 0.20) or any VPT condition (p > 0.20) and was not included in those regression analyses. Years of education did not correlate with VPT self-consistent, other-consistent and other-inconsistent conditions (both p > 0.20) and was not included in the regression analyses for these conditions.

Table 3 provides the regression analyses involving the ESCoT and EF abilities. On cognitive ToM, performance was significantly associated with age group and processing speed. Younger adults and those with slower processing speed showed higher scores on cognitive ToM. On affective ToM, there was a significant relationship between performance and age group and gender. Better performance was associated with being younger and female. Performance on interpersonal understanding of social norms was significantly associated with age group, with younger participants performing better. The regression analysis for intrapersonal understanding of social norms was not statistically significant. There was a significant relationship between ESCoT total score, age group and gender. Being younger and female was associated with better overall ESCoT performance. In all models, EF abilities were not significantly associated with performance on the ESCoT.

[Insert Table 3 here]

Table 4 illustrates the Bayesian ANCOVA analyses. For cognitive ToM, BF_{01} ranged between 1.175 and 7.905 when EF abilities were included, indicating anecdotal to moderate evidence in favour of the null model. For affective ToM, BF_{01} ranged between 6.793 and 32.949 when EF abilities were added, indicating moderate to very strong evidence in favour of the null model. For interpersonal understanding of social norms, when the EF measures were entered into the model, BF_{01} ranged between 2.949 and 22.018, indicating anecdotal to strong evidence in favour of the null model. For intrapersonal understanding of social norms, BF_{01} ranged between 2.918 and 6.733 for the inclusion of EF abilities, providing anecdotal to moderate evidence for the null model. Finally, for the ESCoT total score, BF_{01} ranged between 4.136 and 39.520 when the EF measures were entered into the model, indicating moderate to very strong evidence in favour of the null model.

[Insert Table 4 here]

Table 5 shows the regression analyses for the sub-scores of the VPT. The relationship between higher processing costs and age group in the self-consistent condition was partially mediated by poorer processing speed and updating performance. In the self-inconsistent condition, poorer processing speed and updating fully mediated the relationship between age group and processing costs. Higher processing costs in the other-consistent condition were related to older age, but this relationship was partially mediated by poorer processing speed and updating. There was a significant relationship between higher processing costs and the older age group; however, this relationship was partially mediated by processing speed and updating performance.

[Insert Table 5 here]

Table 6 provides the correlational analyses between the ESCoT and VPT conditions Performance on cognitive ToM positively correlated with performance on interpersonal understanding of social norms, while affective ToM correlated with intrapersonal understanding of social norms. All ESCoT subtests significantly correlated with ESCoT total score. Performance on the cognitive ToM subtest significantly correlated with self-consistent, other-consistent and other-inconsistent processing costs of the VPT. The same significant negative relationships were found between the interpersonal understanding of social norms and ESCoT total scores and self-consistent, other-consistent and other-inconsistent processing costs. All VPT conditions significantly correlated with each other.

[Insert Table 6 here]

Discussion

The current study examined the influence of different EF abilities on performance on the Edinburgh Social Cognition Test (ESCoT). We found that performance on the subcomponents of the ESCoT was not significantly associated with any EF abilities (i.e., inhibition, set-shifting or updating) but instead, age group and gender influenced performance. Processing speed was negatively associated with performance on cognitive ToM. In contrast, age-related associations on the VPT were either fully or partially explained by the relationships with updating and processing speed performance.

Our finding that cognitive ToM performance on the ESCoT was not related to EF abilities is similar to previous findings in the literature (Bernstein et al., 2011; Cavallini et al., 2013; Maylor et al., 2002; Wang & Su, 2013). However, other studies have reported an association between cognitive ToM and EF abilities (Bailey & Henry, 2008; Bottiroli et al., 2016; Duval et al., 2011; German & Hehman, 2006; Johansson Nolaker et al., 2018; Li et al., 2013; Phillips et al., 2011). Some variability in the aging literature in terms of whether EF abilities underlie performance on social cognition measures might be due to different tests being administered with distinct psychometric properties (e.g., Duval et al., 2014; Bailey & Henry, 2008; Henry et al., 2013). Indeed, our own work has shown that ESCoT performance is not associated with perceptual reasoning or verbal comprehension abilities (Baksh et al., 2018) compared to other social cognitive tests (Baker et al., 2014; Charlton et al., 2009; Maylor et al., 2002; Sullivan & Ruffman, 2004). On the VPT, however, performance was fully or partially explained by updating performance but not inhibition and set-shifting. The VPT is likely to be more reliant on updating, as it requires participants to retain, process and respond to information regarding an avatar's perspective. In terms of our EF measures, we selected them to tap the EF abilities proposed by Miyake et al.'s (2000) model, and previous studies have used similar EF tests (Duval et al., 2011; Charlton et al., 2009). Therefore, it is unlikely that our results can be explained by heterogeneity across EF measures.

On affective ToM, we found that EF abilities were not related to performance, which is in line with most previous aging studies (Bottiroli et al., 2016; Duval et al., 2011; Keightley et al., 2006; Mahy et al., 2014; Sullivan & Ruffman, 2004; Wang & Su, 2013). However, Johansson Nolaker et al. (2018) found that updating, gender and cognitive empathy explained 41.7% of the variance on affective ToM performance, suggesting that this ability is not associated with age-related changes. There are some differences between our two tests. In the Strange Stories Film task, participants are asked to make logical reasoning judgments about lies, irony, double bluffs, etc. (Murray et al., 2017) which may be more reliant on EF abilities. The interactions in the ESCoT examine social norm violations and may be less dependent on specific EF abilities. Moreover, in the ESCoT, participants rely on the individual contexts of the animations to inform their answers; indeed, responses are scored more highly if participants include contextual information from the interaction. However, the importance of context is not as explicit in the Strange Stories Film task scoring instructions. Our current findings indicated that the ESCoT has the advantage that poor performance on the different subtests is unlikely to be due to impaired EF abilities. These findings may have implications for social cognition assessment in clinical populations with frontal involvement when one wishes to determine social cognitive impairment independent from dysexecutive syndrome.

The current study replicates our previous findings of a negative association between age and performance on cognitive ToM, affective ToM, interpersonal understanding of social norms and ESCoT total scores (Baksh et al., 2018). Again, being female was associated with better performance on inferring how someone is feeling, which was also found in Johansson Nolaker et al. (2018). Yet, gender does not appear to influence cognitive ToM, or intrapersonal or interpersonal understanding of social norms. While performance on cognitive ToM was significantly related to performance on several VPT measures, we found no significant relationship between affective ToM and VPT performance. These findings provide further evidence of overlapping but distinct aspects of cognitive and affective ToM (Baksh et al., 2018; Sebastian et al., 2012; Shamay-Tsoory et al., 2007). Our results suggest that the VPT should be considered a test of social cognitive abilities, processing speed and EF abilities. Indeed, Qureshi et al. (2010) showed that the performance of a concurrent executive task increased processing costs on all VPT conditions. Here, we provide evidence that the ESCoT is perhaps a purer measure of social cognition that does not tap EF abilities.

The negative relationship between cognitive ToM and processing speed is surprising. Charlton et al. (2009) showed that the relationship between ToM and age on the Strange Stories test is mediated by processing speed, performance IQ and EF abilities and partially mediated by verbal IQ. However, Charlton et al. (2009) found that poorer processing speed was related to poorer cognitive ToM. Here, we found that poorer processing speed was associated with better cognitive ToM on the ESCoT, but poorer processing speed was associated with poorer performance on the VPT. While the mechanisms behind this finding are unclear, one possible explanation is that cognitive ToM inferences take more time to process in social interactions, and thus favour those who take more time to process the information. However, we do not have cognitive ToM response time data to confirm that there is a speed-accuracy trade-off. Another potential explanation is that the coding subtest from the WAIS-IV assesses more than processing speed, and these abilities play an important role when making cognitive ToM inferences in the ESCoT. There is also the possibility that these opposing findings are an artefact of insufficiently powered analyses. Future work should investigate this relationship further using different measures of processing speed in a larger group of participants.

Certain study limitations should be noted. Firstly, while including a middle-aged group would have allowed us to consider age as a continuous variable and increase our statistical power, due to limited resources and time constraints, we focused on studying younger and older adults only. Moreover, although our study was sufficiently powered to detect a medium sized effect of EF abilities on ESCoT performance, our sample size prohibited the reliable estimation of small effects. Regardless, our sample size did permit us to demonstrate an effect of updating on VPT performance. We also present Bayes Factors (BF01) to quantify the extent to which our data support the null hypothesis over the alternative one (Wagenmakers et al., 2017). When comparing the null model including the significant covariates to the alternative models including processing speed and EF abilities, our evidence was in favour of the null model and ranged from anecdotal to very strong evidence. However, there are other measures of cognition which decline with age (Hedden & Gabrieli, 2004), which might show associations with performance on the ESCoT. Future work might consider other cognitive and EF abilities to examine the psychometric properties of the ESCoT and how these affect performance.

Our current study showed that EF abilities are not associated with performance on the ESCoT, at least using our current measures. Only age group and gender predict performance on the task with younger age and being female resulting in better ESCoT performance. However, age-related associations on the VPT are either fully or partially mediated by updating and processing speed. Altogether, our results suggest that the previously reported associations between social cognition and EF abilities may be due to the underlying psychometric properties of the social cognition tests administered. The ESCoT does not appear to tap EF abilities and may provide a purer assessment of distinct social cognitive abilities in the same test.

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Table 1. ESCoT social cognitive domains and questions for each interaction

Social cognitive ability	ESCoT question	Objective of question
Cognitive ToM	What is X thinking?	Measures the ability to infer the thoughts and intentions of the character in the interaction.
Affective ToM	How does X feel at the end of the animation?	Measures the ability to infer the feelings of the character in the interaction.
Interpersonal understanding of social norms	Did X behave as other people should behave?	Measures the ability to understand whether the character in the interaction followed social norms.
Intrapersonal understanding of social norms	Would you have acted the same as X in the animation?	Measures how the participant themselves may have acted in the interaction based on social norms.

Table 2. Demographic information and means and standard deviations (in parentheses) for the cognitive and social cognitive test performance of the younger and older groups

	Younger adults	Older adults	*p* value
Age (years)	22.57 (2.36)	72.29 (3.99)	–
Males: Females	12:18	16:15	YA = 0.27, OA = 0.88
Years of full-time education	16.73 (1.14)	16.12 (3.27)	= 0.22
ECAS total score (max score = 136)	119.70 (6.13)	119.33 (8.03)	= 0.84
D-KEFS colour-word interference test (seconds)	19.27 (5.25)	37.67 (10.84)	< 0.001
Trail Making test (Part B-Part A; seconds)	29.38 (14.74)	43.05 (23.90)	= 0.009
Digit span sequencing (max score = 16)	10.93 (1.61)	9.13 (1.82)	= 0.001
Coding (max score = 135)	83.20 (10.87)	65.19 (19.29)	< 0.001
ESCoT Cognitive ToM (max score = 30)	21.90 (2.00)	20.00 (1.88)	< 0.001
ESCoT Affective ToM (max score = 30)	26.83 (1.88)	25.47 (2.81)	= 0.03
ESCoT Interpersonal understanding of social norms (max score = 30)	24.03 (2.95)	20.07 (2.89)	< 0.001
ESCoT Intrapersonal understanding of social norms (max score = 30)	28.30 (4.43)	27.43 (2.13)	= 0.14
ESCoT Total score (max score = 120)	101.07 (4.43)	92.97 (6.28)	< 0.001
VPT Self-consistent condition processing cost	627.42 (133.66)	917.91 (268.59)	< 0.001
VPT Self-inconsistent condition processing cost	729.09 (170.30)	1022.99 (359.71)	< 0.001
VPT Other-consistent condition processing cost	583.84 (112.92)	881.69 (271.28)	< 0.001
VPT Other-inconsistent condition processing cost	777.57 (194.03)	1142.95 (260.14)	< 0.001

ECAS = Edinburgh Cognitive and Behavioural ALS Screen; D-KEFS = Delis-Kaplan Executive Function System; ToM = Theory of Mind; ESCoT = Edinburgh Social Cognition

Test; VPT = Visual Perspective Taking Task; processing cost = mean time/proportion correct; YA = Younger adults; OA = Older adults. We used the Holm correction to adjust for multiple comparisons.

Table 3. Summary of multiple regression analyses for the ESCoT and EFs

	Cognitive ToM	Affective ToM	Interpersonal understanding of social norms	Intrapersonal understanding of social norms	ESCoT total score
Model 1	$R^2 = 0.18$, $f(1, 58) = 12.27$, $p = 0.001$	$R^2 = 0.25$, $f(2, 57) = 9.41$, $p < 0.001$	$R^2 = 0.34$, $f(2, 57) = 14.88$, $p < 0.001$	$R^2 = 0.10$, $f(2, 57) = 3.10$, $p = 0.05$	$R^2 = 0.43$, $f(2, 57) = 21.31$, $p < 0.001$
	Age group (β = - 0.04, SE = 0.01, ***p* = 0.002**)	Age group (β = - 0.03, SE = 0.01, *p* = **0.03**), gender (β = 1.92, SE = 0.57, *p* = **0.001**)	Age group (β = - 0.08, SE = 0.02, *p* < **0.001**), gender (β = 0.56, SE = 0.76, *p* = 0.47)	Age group (β = - 0.02, SE = 0.009, *p* = 0.06), gender (β = 0.59, SE = 0.46, *p* = 0.20)	Age group (β = - 0.02, SE = 0.03, *p* < **0.001**), gender (β = 2.85, SE = 1.36, *p* = **0.04**)
Model 2	$R^2 = 0.25$, $f(2, 57) = 9.30$, $p < 0.001$	–	–	–	–

F–change = 5.40, $p = 0.02$, $\Delta R^2 = 0.07$	
Age group ($\beta = -0.05$, SE = 0.01, $p <$ **0.001**), processing speed ($\beta = -0.04$, SE = 0.02, $p =$ **0.02**)	

ToM = theory of mind; ESCoT = Edinburgh Social Cognition Test; Model 1 = age group, gender, years of education; Model 2 = processing speed; Model 3 = EF abilities (inhibition, set-shifting and updating); Bold text indicates statistical significant associations. The Holm correction for multiple comparisons was applied.

Table 4. Summary of Bayes ANCOVA for the ESCoT and EFs

	Model	P(M)	P(M|data)	BF_M	BF_{01}	% error
Cognitive	Null model (Age group)	0.063	0.114	1.924	1.000	
ToM	Processing speed	0.063	0.307	6.658	0.370	0.006
	Processing speed + updating	0.063	0.097	1.606	1.175	0.004
	Processing speed + set-shifting	0.063	0.096	1.599	1.180	0.004
	Processing speed + inhibition	0.063	0.096	1.598	1.181	0.004
	Processing speed + updating + set-shifting	0.063	0.035	0.550	3.215	0.004
	Processing speed + updating + inhibition	0.063	0.035	0.548	3.225	0.004
	Processing speed + set-shifting + inhibition	0.063	0.035	0.545	3.241	0.004
	Processing speed + updating + set-shifting + inhibition	0.063	0.014	0.219	7.905	0.004
Affective	Null model (Age group + Gender)	0.063	0.293	6.228	1.000	
ToM	Processing speed	0.063	0.104	1.737	2.828	0.003
	Processing speed + updating	0.063	0.038	0.599	7.638	0.003
	Processing speed + set-shifting	0.063	0.043	0.677	6.793	0.003

	Processing speed + inhibition	0.063	0.038	0.593	7.713	0.003
	Processing speed + updating + set-shifting	0.063	0.020	0.309	14.546	0.003
	Processing speed + updating + inhibition	0.063	0.016	0.242	18.493	0.003
	Processing speed + set-shifting + inhibition	0.063	0.017	0.266	16.844	0.003
	Processing speed + updating + set-shifting + inhibition	0.063	0.009	0.135	32.949	0.012
Interpersonal understanding of social norms	Null model (Age group + Gender)	0.063	0.215	4.109	1.000	
	Processing speed	0.063	0.216	4.143	0.994	0.001
	Processing speed + updating	0.063	0.073	1.180	2.949	0.001
	Processing speed + set-shifting	0.063	0.065	1.041	3.313	0.002
	Processing speed + inhibition	0.063	0.064	1.034	3.334	0.002
	Processing speed + updating + set-shifting	0.063	0.027	0.409	8.092	0.002
	Processing speed + updating + inhibition	0.063	0.024	0.376	8.804	0.002
	Processing speed + set-shifting + inhibition	0.063	0.022	0.335	9.834	0.002
	Processing speed + updating + set-shifting + inhibition	0.063	0.010	0.148	22.018	0.002

Intrapersonal understanding of social norms	Null model (Age group + Gender)	0.063	0.151	2.667	1.000	
	Processing speed	0.063	0.059	0.947	2.541	0.002
	Processing speed + updating	0.063	0.046	0.727	3.264	0.004
	Processing speed + set-shifting	0.063	0.052	0.818	2.918	0.004
	Processing speed + inhibition	0.063	0.033	0.517	4.527	0.004
	Processing speed + updating + set-shifting	0.063	0.029	0.442	5.274	0.010
	Processing speed + updating + inhibition	0.063	0.033	0.518	4.520	0.009
	Processing speed + set-shifting + inhibition	0.063	0.035	0.546	4.295	0.008
	Processing speed + updating + set-shifting + inhibition	0.063	0.022	0.344	6.733	0.012
ESCoT Total Score	Null model (Age group + Gender)	0.063	0.265	5.412	1	
	Processing speed	0.063	0.188	3.477	1.409	1.988e -4
	Processing speed + updating	0.063	0.050	0.782	5.350	9.463e -5
	Processing speed + set-shifting	0.063	0.064	1.028	4.136	7.718e -5
	Processing speed + inhibition	0.063	0.050	0.792	5.286	9.365e -5
	Processing speed + updating + set-shifting	0.063	0.020	0.308	13.193	1.650e -4
	Processing speed + updating + inhibition	0.063	0.015	0.229	17.660	2.069e -4

Processing speed + set-shifting + inhibition	0.063	0.020	0.300	13.503	1.678e -4
Processing speed + updating + set-shifting + inhibition	0.063	0.007	0.101	39.520	1.704e -4

ToM = theory of mind; ESCoT = Edinburgh Social Cognition Test

Table 5. Summary of multiple regression analyses for the Visual Perspective Taking task and EF abilities

	Self-consistent condition processing cost	Self-inconsistent condition processing cost	Other-consistent condition processing cost	Other-inconsistent condition processing cost
Model 1	$R^2 = 0.35$, $f(1, 57) = 30.15$, $p < 0.001$	$R^2 = 0.23$, $f(2, 55) = 8.00$, $p = 0.001$	$R^2 = 0.38$, $f(1, 57) = 34.41$, $p < 0.001$	$R^2 = 0.44$, $f(1, 56) = 43.52$, $p < 0.001$
	Age group (β = 5.97, SE = 1.09, *p* < **0.001**)	Age group (β = 5.93, SE = 1.48, *p* **< 0.001**), education (β = 5.37, SE = 15.06, *p* = 0.72)	Age group (β = 6.20, SE = 1.06, *p* < **0.001**)	Age group (β = 7.65, SE = 1.16, *p* < **0.001**)
Model 2	$R^2 = 0.45$, $f(2, 56) = 23.31$, $p < 0.001$	$R^2 = 0.37$, $f(3, 54) = 10.40$, $p < 0.001$	$R^2 = 0.47$, $f(2, 56) = 24.83$, $p < 0.001$	$R^2 = 0.50$, $f(2, 55) = 26.91$, $p < 0.001$
	F–change = 11.12, $p = 0.002$, $\Delta R^2 = 0.11$	F–change = 12.00, $p = 0.001$, $\Delta R^2 = 0.14$	F–change = 9.90, $p = 0.003$, $\Delta R^2 = 0.09$	F–change = 6.23, $p = 0.02$, $\Delta R^2 = 0.06$

	Age group (β = 3.81, SE = 1.19, *p* = **0.01**) & processing speed (β = - 5.51, SE = 1.65, *p* = **0.01**)	Age group (β = 2.99, SE = 1.60, *p* = 0.07), education (β = 2.36, SE = 13.77, *p* = 0.87), processing speed (β = - 7.83, SE = 2.26, *p* = **0.003**)	Age group (β = 4.20, SE = 1.17, *p* = **0.005**), processing speed (β = - 5.10, SE = 1.62, *p* = **0.01**)	Age group (β = 5.93 SE = 1.31, *p* < **0.001**), processing speed (β = - 4.73, SE = 1.90, *p* = **0.03**)
Model 3	$R^2 = 0.53$, $f(3, 55) = 20.66$, $p < 0.001$	$R^2 = 0.46$, $f(4, 53) = 11.11$, $p < 0.001$	$R^2 = 0.55$, $f(3, 55) = 21.97$, $p < 0.001$	$R^2 = 0.55$, $f(3, 54) = 22.25$, $p < 0.01$
	F–change = 8.84, $p = 0.004$, $\Delta R^2 = 0.08$	F–change = 8.77, $p = 0.005$, $\Delta R^2 = 0.09$	F–change = 9.89, $p = 0.004$, $\Delta R^2 = 0.08$	F–change = 7.04, $p = 0.01$, $\Delta R^2 = 0.06$
	Age group (β = 2.82, SE = 1.17, *p* = **0.02**), processing speed (β = -4.70, SE = 1.57, *p* = **0.01**) &	Age group (β = 1.52, SE = 1.57, *p* = 0.34), years of education (β = 2.25, SE =	Age group (β = 3.22, SE = 1.54, *p* = **0.01**), processing speed (β = - 4.29, SE = 1.54, *p* = **0.01**) &	Age group (β = 4.90, SE = 1.30, *p* = **0.001**), processing speed (β = - 3.97, SE = 1.82, *p* = **0.03**) &

updating (β = - 42.92, SE = 14.43, *p* = **0.01**)	12.88, *p* = 0.86), processing speed (β = - 7.07, SE = 2.12, *p* = **0.004**) & updating (β = - 59.10, SE = 19.96, *p* = **0.005**)	updating (β = - 42.56, SE = 14.13, *p* = **0.01**)	updating (β = - 42.55, SE = 16.04, *p* = **0.03**)

Model 1 = age group, gender, years of education; Model 2 = processing speed; Model 3 = EF abilities (inhibition, set-shifting and updating). Bold text indicates statistical significant associations. The Holm correction for multiple comparisons was applied.

Table 6. Summary of correlational analyses between the ESCoT and VPT conditions

	Affective ToM	Interpersonal understanding of social norms	Intrapersonal understanding of social norms	ESCoT total	Self-consistent condition processing cost	Self-inconsistent condition processing cost	Other-consistent condition processing cost	Other-inconsistent condition processing cost
Cognitive ToM	0.17	0.30*	0.11	0.60***	-0.30*	-0.22	-0.32*	-0.34*
Affective ToM		0.25	0.33*	0.61***	-0.08	-0.07	-0.13	-0.09
Interpersonal understanding of social norms			0.42**	0.80***	-0.35*	-0.20	-0.31*	-0.37*
Intrapersonal understanding of social norms				0.61***	-0.08	-0.007	-0.008	0.10
ESCoT total					-0.35*	-0.22	-0.33*	-0.37*
Self-consistent condition processing cost						0.88***	0.92***	0.86***
Self-inconsistent condition processing cost							0.82***	0.78***
Other-consistent condition processing cost								0.87***

ToM = theory of mind; ESCoT = Edinburgh Social Cognition Test. Bold text indicates statistical significance. The Holm correction for multiple comparisons was applied. NOTE. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$